Polarized Neutrons for Condensed Matter Investigations at PNPI

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The main characteristics of the neutron facility at PNPI, Reactor WWR-M, read as follows. It has a power of 16 MWt and a thermal neutron flux of 10^{14}n/cm^{-2} s^{-1}. The rector is surrounded by 20 neutron instruments and 10 of them operate with polarized neutrons. 12 instruments are particularly devoted to the Condensed Matter investigations and 6 setups are equipped with polarization analysis. These instruments, their feature, and main results are counted below [1]:

1 **SAPNS-VECTOR.** The small angle polarized neutron scattering setup operates within the range of λ from 8 to 12 Å ($\Delta\lambda/\lambda = 0.1$) governed by the magnetic space resonance monochromator. It is equipped by the 20 – channel detector system with a mirror-analyzer in front of it. The method of 3-d analysis of scattered neutrons was developed. It allows separation of the magnetic and nuclear scattering as well as separation of the elastic and inelastic magnetic scattering. Furthermore the method of the dynamical 3-spin correlation (left-right asymmetry of polarized neutrons scattering) was discovered and added to one's arsenal.

2 **- 3DAPN.** The setup of 3-d analysis of PN in the transmitted beam operates at λ=2.2 Å and allows determination of **P** direction in the space with an accuracy of 1%. The methods of Larmor precession and the study of magnetic texture are whidely using on this instrument. At present the module of spin-echo-SANS (SESANS) is under construction on this instrument for study of large-scale magnetic and nonmagnetic structures (momentum transfer q=10^{-4} -10^{-5} Å^{-1}).

3 **- CSPN.** Correlation spectrometer of PN operates at λ=2.5 Å, $\Delta\lambda/\lambda = 0.04$. It is based on the time-of-flight techniques with pseudo-random modulation of neutron beam polarization and the scheme of reverse geometry. The Geysler's crystal is used as an analyzer and allows measurements in the spin flip (SF) and with non spin flip (SNF) modes.

4 - **TOFRPN - TOF reflectometer**: It operates at λ = 1-4 Å, $\Delta\lambda/\lambda$=0,1-0,025, and is equipped with mirror polarizer and analyzer (CoFe on TiGd), P > 0.98. It is devoted to the test experiments of optical equipment manufactured in PNPI.

5 - **MSES - Modifyed spin-echo spectrometer.** It operates at λ = 6.5 Å with the incident polarization of P > 0.95. In modification mode one uses modulation of the spectrum by the phase of neutron spin precession and can investigate the magnetic samples.

6 **ReVerANS – Reflectometer with Vertical Angle of Neutron Scattering.** At present it is under construction. It will operate at λ = 4 Å with vertical plane of scattering. It is constructed for investigations of the free surface of liquids.

A substantial part of experiments on the SAPNS-VECTOR setup is connected with the studies of magnetic phase transitions using 3D analysis of **scattered neutrons**. It allows separation of the magnetic and nuclear scattering as well as separation of the elastic and inelastic magnetic scattering using the relation $\mathbf{P}=-\mathbf{e}(\mathbf{e}\mathbf{P}_0)$, where $\mathbf{e}=\mathbf{q}/q$ [2,3]. The critical indexes for Fe were obtained with high accuracy [4,5]: ν=0.67(1) and z=2.627(4) in a temperature range $\tau=(T-T_C)/T_C=10^{-4}-5\cdot10^{-2}$. From the inelastic part a deviation of the form-factor of the critical scattering from Lorentzian was found.

Furthermore, the theoretical prediction [6] on the neutron depolarization anisotropy in magnetically isotropic system $A=\ln(P_\perp/P_{0\perp})/(P_\parallel/P_{0\parallel})=3/2$ ("3/2 rule") was confirmed experimentally [7] where signs $\perp$ and $\parallel$ denote the components of polarization perpendicular and parallel to the beam, respectively. 3D analysis of the transmitted beam was used for investigation of the internal field distribution in HTC superconductors. The distribution of field **B** penetrated in YBaCuO sample was visualized. The trapped field and the current density were calculated from gradient of **B** [8].

The small effect of the three spin dynamical chiral correlator $\langle S^\alpha_1(t_1)S^\beta_2(t_2)S^\gamma_3(t_3)\rangle$ predicted theoretically [9] has been observed experimentally [10] in critical scattering on Fe above T_C. At small angle scattering ω-integrated chiral contribution to the cross section is zero in conventional experiments due to t-parity. In the case of so-called "inclined geometry", when magnetization **M** (and $\mathbf{P_0}$) is directed at angle $\varphi\neq0$ (or $\pi/2$) to the incident neutron beam, the parity changes and left-right asymmetry of inelastic scattering appears [11]. We use this method to study the dynamical chirality of critical spin fluctuation above T_C and spin-wave excitations below T_C. The number of unusual new results was obtained [12]. Among them: i) the confirmation of the Polyakov-Kadanoff-Wilson algebra [13], where exists a general theoretical prediction on the asymptotic behavior of the many-spin correlation function, ii) the crossover to dipolar spin dynamics just above T_C , iii) confirmation of "hard" variant of dipole dynamics [12], where energy of critical fluctuations in dipole region is $\Omega_d \sim q_0^{3/2} q$ instead of $\Omega_d \sim q_0^{1/2} q^2$ in convention variant (here q_0 is dipole impulse). Using this method we studied the spin-wave dynamics below T_C in amorphous alloys [14, 15] , invars [16], etc.

The static helix structure was investigated on the single crystal MnSi with the Dzyaloshinskii-Moria interaction [17]. The following results were obtained: 1) the helicity is left – handed; 2) the critical field of the magnetic transition from helix to ferromagnetic state H_c = 570 mT ; 3) helix vector **Q**||[111] at H=0 only and it rotates to **H** at $0<H<H_{c1}$ and **Q** || **H** at $H \geq = H_{c1}$ = 120÷130 mT; 4) helix period is temperature dependent $d=d_o f(T)$ with d_0= 182 Å; 5) spin wave stiffness $D(T)=D_0(1-c(T/T_C)^z)$, with D_0=50 meVÅ^2 , c=0.035±0.006 and z=2.4±0.1.

A number of successful experiments were performed for investigation of the spin chirality in the triangular-lattice antiferromagnets [18]. H. Kawamura proposed a hypothesis that triangular antiferromagnets belong to a new universality class of the second order phase transition. This means that there must exist new chiral critical exponents of $|\tau| = (T-T_N)/T_N$: specific heat $C \sim \tau^{-\alpha}$, susceptibility $\chi \sim \tau^{-\gamma}$, order parameter $M \sim (-\tau)^{\beta}$, and the correlation length $\xi \sim \tau^{-\nu}$. The scaling relation between these exponents ($\alpha+2\beta+\gamma=2$) must be fulfilled. For the triangular-lattice antiferromagnet CsMnBr3 [18] the following values were obtained: β_c = 0.44(2), γ_c = 0.84(7). Taking into account α=0.40(5) it was obtained that $\alpha+2\beta c+\gamma c$=2.12(9). These results confirm Kawamura's predictions of a new universality class of the chiral phase transition.

Many others interesting results were obtained in cooperation with others institutes [19-22].

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